# 〈Research Reports〉 Channel initiation in a mountain basin underlain by granodiorite : A case study in the Abukuma Mountains, Japan



| | |
|---|---|
| 著者 | Hattanji Tsuyoshi, Matsushi Yuki |
| journal or publication title | Tsukuba geoenvironmental sciences |
| volume | 7 |
| page range | 19-23 |
| year | 2011-12-26 |
| URL | http://hdl.handle.net/2241/116872 |

Tsukuba Geoenvironmental Sciences, Vol. 7, pp. 19-23, Dec. 26, 2011

# Channel initiation in a mountain basin underlain by granodiorite: A case study in the Abukuma Mountains, Japan

Tsuyoshi HATTANJI* and Yuki MATSUSHI**

**Abstract**

Hydrogeomorphic characteristics of channel heads were examined in a mountain basin underlain by granodiorite, located in Abukuma Mountains, southern Tohoku region. Source area, local slope, and altitude were measured at 23 channel heads. Hydrological observation revealed stable stream runoff, indicating predominance of groundwater flow. Geomorphic investigation showed a scattered area-slope relationship at channel heads. These results correspond with the previous findings that channel initiation is not controlled by area-slope thresholds in the areas where contribution of groundwater flow to stream runoff is greater. Altitude distribution of channel heads for the investigated area does not support the hypothesis of critical altitude on channel initiation.

**Key words:** channel initiation, granodiorite, groundwater flow, runoff processes

## 1. Introduction

Channel initiation is a key process for landscape evolution in mountains. Dunne (1980) and Dietrich and Dunne (1993) suggested that channel initiation is strongly affected by runoff processes under various climatic and lithological conditions. In humid forested mountains, major runoff processes are Sub-Surface Storm Flow in regolith upon impermeable bedrock (SSSF), and Ground-Water Flow within permeable or fractured bedrock (GWF). Hattanji and Matsushi (2006) investigated hydrogeomorphic conditions for channel heads in four humid forested mountains with different lithologies, and classified channel initiation into SSSF and GWF types based on these primary runoff processes. SSSF-type channel initiation is controlled by local slope and topographic source area estimated from surface topography. Channel initiation for this case is explained with the area-slope threshold model (Montgomery and Dietrich, 1988, 1989, 1994), which predicts inverse area-slope relationships at channel heads.

In contrast, topographic source area is not a controlling factor for GWF-type channel initiation. One of the reasons would be the effect of geological structure in bedrock, such as fracture systems or heterogeneity on groundwater flow system (Laity and Malin, 1985; Dietrich *et al*., 1987; Montgomery and Dietrich, 1994). The previous study (Hattanji and Matsushi, 2006) revealed that GWF-type channel heads develop only in lower altitude zones within the entire basin, and suggested a hypothesis of critical altitude in GWF-type channel initiation. However, these results were based on four areas underlain by sedimentary rocks with different formation ages (middle Pleistocene/Mesozoic). To improve our understanding of hydrological control on channel initiation, the results of Hattanji and Matsushi (2006) should be evaluated in other areas with different rock types, such as granitic rocks. This paper summarizes preliminary results of hydrological and geomorphic investigations on channel heads in a mountain basin underlain by granodiorite.

## 2. Site description

### 2.1 Climatic and geological settings

The investigated basin is a western part of Mt. Hayama in the Abukuma Mountains, southern Tohoku region (Fig. 1). The bedrock of Mt. Hayama is composed of hornblende-biotite granodiorite. The mean temperature and the mean annual rainfall for 30-year records (1981–2010) are 10.5 °C and 1245 mm at the Japan Meteorologi-

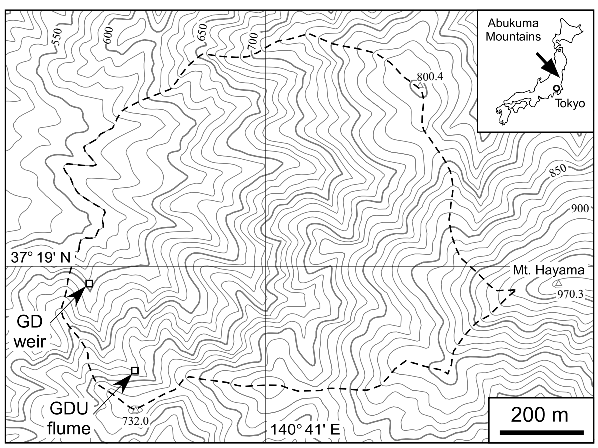


Fig. 1 Topographic map of the investigated area. The open squares indicate the observation sites for stream runoff. Contour interval is 10 m.

* Graduate School of Life and Environmental Sciences, University of Tsukuba
** Disaster Prevention Research Institute, Kyoto University

cal Agency station, Ononiimachi (7-km SW of the study site). The investigated site has smaller amount of annual rainfall and lower temperature compared to the four sites of Hattanji and Matsushi (2006). Planted forests of cedar (*Cryptomeria japonica*) and cypress (*Chamaecyparis obtusa*) mainly cover the investigated basin, and broad-leaved deciduous forests partly remain high altitude zones (> 750 m a.s.l.).

### *2.2 Properties of regolith and bedrock*

Hirose *et al*. (1994) reported that the regolith has a depth of 1–2 m in a small watershed within the study area (GD watershed in Fig. 1). Terada *et al*. (1994) reported that the grus regolith in the GD watershed is composed of gravel of 15%, sand of 70%, and silt and clay of 15%. A saprolite sample taken below the regolith (1.2-m depth) has a hydraulic conductivity of $4.7 \times 10^{-5}$ m s$^{-1}$. This value roughly corresponds to the fractured bedrock ($1.7 \times 10^{-5}$ m s$^{-1}$) of sandstone in the Ashio Mountains, or weathered sandstone bedrock ($2 \times 10^{-5}$ m s$^{-1}$) in Mt. Kanozan (Hattanji and Matsushi, 2006), implying predominance of groundwater flow pathway within weathered bedrock in this area.

## 3. Methods

### *3.1 Hydrological observation and analysis*

Stream discharge immediately below a channel head (GDU, Fig. 1) was observed with a flume from June 25 to December 4, 2004. The drainage area of GDU site is 5670 m$^2$. Flow depth in the flume monitored with a capacitive water-depth sensor was converted into discharge. Data interval is 10 min. The component of quick flow immediately after rainfall was separated from the total runoff using a line with the slope of 0.55 L s$^{-1}$ km$^{-2}$ hour$^{-1}$ from the onset of storm runoff (Hewlett and Hibbert, 1967). Then, the ratio of quick flow to precipitation (*QF*/*P*) is calculated as an index for the magnitude of SSSF, to compare the results of the previous study (Hattanji and Matsushi, 2006).

### *3.2 Geomorphological investigation of channel heads*

Distribution and topographic attributes of channel heads in the study area were investigated from 2002 to 2004. We judged the channel heads in situ based on the morphology, following the definition of channel head suggested by Dietrich and Dunne (1993), that is, '*the upstream boundary of concentrated water flow and sediment transport between definable banks*'. The locations of 24 channel heads were indentified using an altitude meter, and plotted on a 1:10,000 topographic map. Source area of a channel head, *A*, was measured on the base map with graphic software. Head slope $S_h$, and channel gradient $S_c$, were defined as local gradients from a channel head to 10-m upstream and downstream points, respectively. Gradients ($S_h$ and $S_c$) were measured in situ with a hand compass at each channel head. We could not measure $S_c$ at one channel head because of a road located immediately downstream, and this channel head was excluded from the subsequent analyses. To compare the results with those of the previous study (Hattanji and Matsushi, 2006), we have analyzed (1) relationship between local gradients ($S_h$ and $S_c$) and source area (*A*) and (2) altitude distribution for 23 channel heads.

## 4. Results and discussion

Here we evaluate the findings of the previous study (Hattanji and Matsushi, 2006), using the results from a basin underlain by granodiorite in the Abukuma Mountains. The previous study revealed the following two results: (1) the coefficient of correlation for area-slope relations at channel heads approaches to –1 with increasing *QF*/*P* and (2) channel heads develop only in lower altitude zones for the case of *QF*/*P*~0%, implying a control of critical altitude for channel initiation related to groundwater flow (GWF).

### *4.1 Hydrological data*

Figure 2 shows a hydrograph at GDU for a period in 2004 including rainy season. Total rainfall for the observation period was 939 mm at Ononiimachi, which is about 200-mm smaller than the other previous study sites for the same period (Hattanji and Matsushi, 2006). Stream flow at the channel head (GDU) was relatively stable throughout the observation period (Fig. 2). The maximum discharge (0.54 L s$^{-1}$; equivalent to specific discharge of $9.6 \times 10^{-8}$ m s$^{-1}$) was observed during a typhoon storm event with 96-mm rainfall on October 9. The sum of quick flow (*QF*) for the entire observation period was 6.0 mm, and the *QF*/*P* was only 0.64% for the entire period.

Hattanji *et al*. (1999) observed stream discharge at a second order stream (GD catchment; 41,000 m$^2$) downstream of the channel head site (GDU). The value of

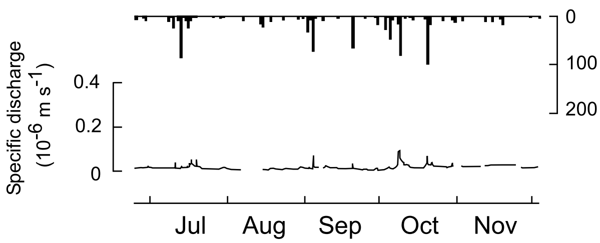


Fig. 2 Hydrograph at a channel head (GDU) from 25 June to 4 December, 2004. Note that specific discharge is discharge divided by drainage area.

*QF/P* was 3.4% for a period of May 21 to November 21, 1998, though the value does not include one extreme flood (329-mm rainfall for four days) in the end of August because of the data lack. The annual rainfall in 1998 records the maximum for 35 years (1976 – 2010) and the value of *QF/P* may be significantly larger than the annual mean value. Hirose *et al*. (1993) observed runoff at GD site from 10 to 21 in July 1991, and the mean *QF/P* was about 2.8% based on their data (Fig. 6 in Hirose *et al*., 1993). Thus, the investigated area has the *QF/P* of 0.64 – 3.4%. This range is significantly smaller than the range of *QF/P* for the three sites of the previous study (13 – 44%), except for the sandstone site of Mt. Kanozan where no storm runoff was observed (*QF/P* = 0%). This result implies that SSSF is not effective and a degree of GWF contributes to the stream flow at GDU catchment. This implication also agrees with subsurface water responses observed by Hirose *et al*. (1994), who confirmed subsurface water percolation without distinct generation of SSSF during a series of storm events near a channel head in GD catchment.

### *4.2 Geomorphic characteristics of channel heads*

Most channel heads are located at the foot of hollows with perennial springs, which drain groundwater throughout year (Fig. 3). Seepage erosion is a major process for channel initiation except for a few channel heads with shallow landslides. These characteristics likely correspond to channel heads in the sandstone area of the Ashio Mountains (Hattanji and Matsushi, 2006). Large boulders were accumulated along two first-order streams in higher altitude zones (> 750 m a.s.l., Fig. 3), but they do not directly influence the topographic attributes of channel heads because the upstream ends of boulder accumulation was at least 70-m away from the channel heads.

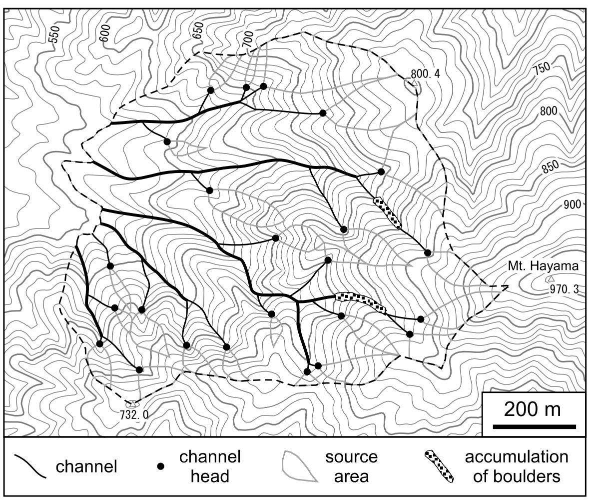


Fig. 3 Distribution of channel heads in the investigated area. Source area represents topographic contributing area for each channel head.

The $S_c/S_h$ ratio indicates the sharpness of gradient transition at a channel head. A small $S_c/S_h$ ratio ($S_c/S_h$ << 1) indicates a distinct decrease in gradient from slope to channel, while the ratio of ~ 1 means smooth gradient transition from slope to channel. The $S_c/S_h$ ratio in this study area ranges from 0.38 to 1.02, and the median is 0.59. These data are approximated to the sandstone area in the Ashio Mountains (Hattanji and Matsushi, 2006), indicating moderate transition of slopes at channel heads.

### *4.3 Area-slope relationship at channel heads*

Source area of channel heads, $A$ (m$^2$) was plotted against local slopes at channel heads (Fig. 4). Most plots showed that source areas decrease with increasing $S_h$, except for two channel heads with very small source area and gentle slope (Fig. 4a). The least-squares regression of log $A$ on $S_h$ yield following equations:

$$A = 570\ S_h^{-3.5} \quad (R^2 = 0.42, p < 0.01) \tag{1}$$

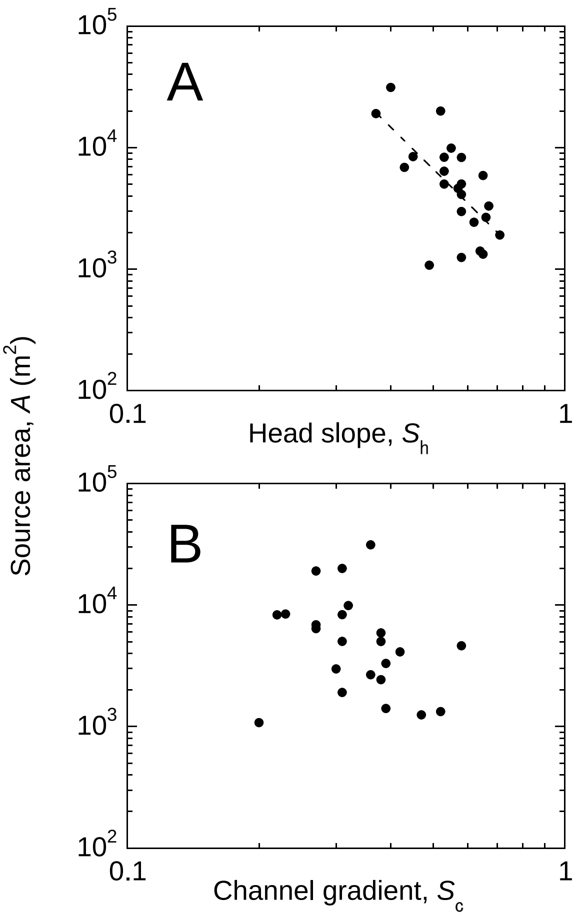


Fig. 4 Relationships between local slope and source area at channel heads. (A) head slope vs source area, (B) channel gradient vs source area. The dashed line indicates the result of regression analysis for the $A$–$S_h$ relationship. The $A$–$S_c$ relationship is not statistically significant.

In the $A$–$S_c$ plots (Fig. 4b), however, channel heads in the investigated area showed a weak negative trend. The statistical analysis indicated the $R^2$ of 0.08 and $p$-value of 0.19, suggesting that the $A$–$S_c$ relation is not statistically significant under a significance level of 0.05.

The obtained coefficients of correlation for area-slope relations at channel heads (Fig. 4) were plotted against $QF/P$ for both the year of 2004 at GDU site and the year of 1999 at GD site (Fig. 5). The two values of $QF/P$ (0.64 – 3.4%) in the investigated area are intermediate of the two sandstone areas of Mt. Kanozan and the Ashio Mountains in the previous study (Hattanji and Matsushi, 2006). The relationship between local channel gradient ($S_c$) and source area ($A$) is not significant, and correlation of local head slope ($S_h$) and source area ($A$) is relatively low for the investigated area. These results well fit to the plots of area-slope correlation against $QF/P$ in the previous study (Hattanji and Matsushi, 2006). Predominance of groundwater flow reduces the effect of surface topographic convergence on stream discharge, which controls sediment transport or landsliding at channel heads. Consequently, the area-slope threshold model cannot be applied to channel initiation in the investigated area.

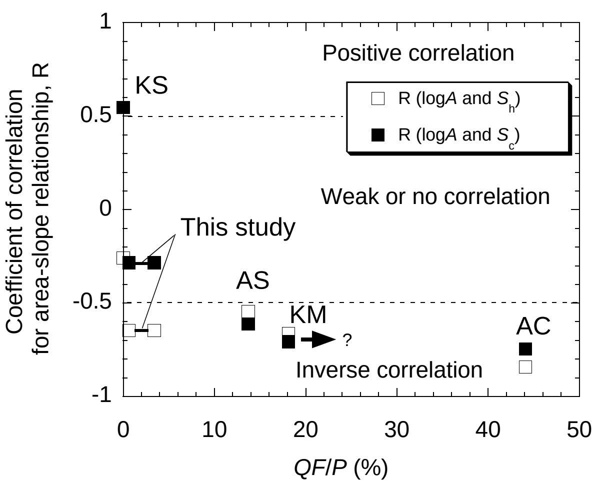


Fig. 5 Coefficient of correlation for area-slope relationship at channel heads plotted against ratio of quick flow to precipitation ($QF/P$). AC and AS are chert area and sandstone area in the Ashio Mountains; KM and KS are mudstone area and sandstone area in Mt. Kanozan (Hattanji and Matsushi, 2006).

### *4.4 Altitude distribution of channel heads*

Figure 6 shows the number of channel heads for each altitude zone (every 20 m contour) with hypsometric curve, i.e. cumulative area-frequency curve. Channel heads in the investigated area were widely distributed in almost entire altitude zones (Fig. 6). To evaluate statistical significance in altitude distribution of channel heads, we carried out a Chi-square ($\chi^2$) test of goodness of fit. The null hypothesis is that channel heads develop evenly regardless of altitude (Hattanji and Matsushi, 2006). For the investigated area, the null hypothesis was not rejected at a significance level of $\alpha = 0.01$, since the calculated $\chi^2$ statistic (11.5) was smaller than the critical $\chi^2$ value (34.8). This result indicates that channel heads develop evenly regardless of altitude, in other words, altitude is not a contributing factor for channel initiation.

The result of Chi-square test for the investigated area does not support the hypothesis of critical altitude for channel initiation (Hattanji and Matsushi, 2006). This hypothesis is based on an idea that seepage erosion occurs in the lower altitude zones within a basin where groundwater can seep, assuming single groundwater flow system within the basin. A possible reason for the inconsistency between the results and the hypothesis would be an effect of multiple groundwater flow systems. Since the dense intact bedrock of granodiorite is impermeable, groundwater mainly flows within permeable weathered bedrock (saprolite), which may not be spatially uniform across the mountain (Endo and Kimiya, 1987). For this case, location of channel heads depends on the distribution of partial groundwater flow systems, which may be formed even in a higher altitude zone of the investigated area. More detailed investigations will be required to verify these implications.

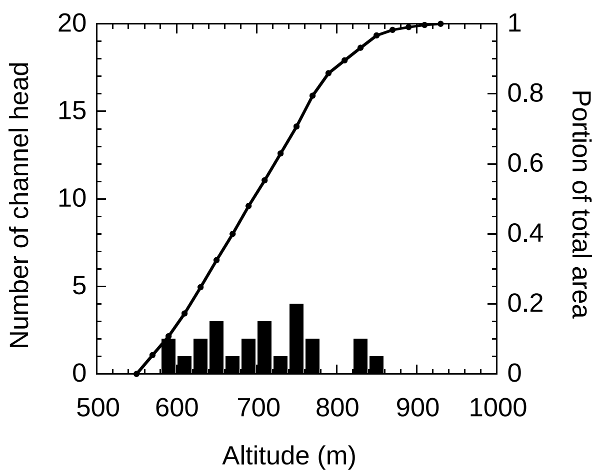


Fig. 6 Altitude distribution of channel heads with hypsometric curves of the investigated area. The altitude axis was not normalized here to show an actual distribution of altitude for channel heads.

## 5. Summary

Results of hydrogeomorphic investigations in a mountain basin underlain by granodiorite in the Abukuma Mountains are summarized as follows: (1) quick flow to total runoff is small (0.64 – 3.4%), indicating a larger contribution of groundwater flow to the runoff, (2) relationship between local channel gradient and source area at channel heads was scattered, and (3) channel heads develop regardless of altitude. The first and second results well correspond with the result of Hattanji and Matsushi (2006) that more scattered area-slope correlation emerges in the areas where contribution of groundwater flow is greater. However, the third result does not support the Hattanji and Matsushi's (2006) hypothesis that critical altitude controls the location of channel heads in areas where groundwater flow predominates. Although it is not obvious what controls the location of channel heads in the investigated area, the third result reveals that the hypothesis of critical altitude in channel initiation must be carefully evaluated using more examples.

**Acknowledgements**

This study was supported financially by the Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists in 2003–2004 held by T. Hattanji.

**References**

Dietrich, W.E. and Dunne, T. 1993. The channel head. In *Channel Network Hydrology*, ed. K. Beven and M.J. Kirkby, 175–219. Chichester: Wiley.

Dietrich, W.E., Reneau, S.L. and Wilson, C.J. 1987. Overview: “zero-order basins” and problems of drainage density, sediment transport and hillslope morphology. *International Association of Hydrological Sciences Publication* **165**, 27–37.

Dunne, T. 1980. Formation and controls of channel networks. *Progress in Physical Geography* **4**, 211–239.

Endo, N. and Kimiya, K. 1987. Distribution of weathering crust of granitic rocks and alteration of biotite in the middle of Abukuma Mountains, Northeastern Japan. *Journal of the Japan Society of Engineering Geology* **28**, 101–114 (in Japanese with English abstract).

Hattanji, T. and Matsushi, Y. 2006. Effect of runoff processes on channel initiation: comparison of four forested mountains in Japan. *Transactions, Japanese Geomorphological Union* **27**, 319–336.

Hattanji, T., Hirose, T. and Matsukura, Y. 1999. Relationship between groundwater fluctuation and sediment yield in a small valley head made of granodiorite in the Abukuma Mountains. *Bulletin of Environmental Research Center, the University of Tsukuba* **24**, 39–47 (in Japanese).

Hewlett, J.D. and Hibbert, A.R. 1967. Factors affecting the response of small watersheds to precipitation in humid areas. In *Forest Hydrology*, ed. W.E. Sopper and H.W. Lull, 275–290. Oxford: Pergamon.

Hirose, T., Onda, Y. and Matsukura, Y. 1993. Runoff characteristics in four small catchments with different bedrocks. *Bulletin of Environmental Research Center, the University of Tsukuba* **17**, 57–64 (in Japanese).

Hirose, T., Onda, Y. and Matsukura, Y. 1994. Runoff and solute characteristics in four small catchments with different bedrocks in the Abukuma Mountains, Japan. *Transactions, Japanese Geomorphological Union* **15A**, 31–48.

Laity, J.E. and Malin, M.C. 1985. Sapping processes and the development of theater-headed valley networks on the Colorado Plateau. *Geological Society of America Bulletin* **96**, 203–217.

Montgomery, D.R. and Dietrich, W.E. 1988. Where do channels begin? *Nature* **336**, 232–234.

Montgomery, D.R. and Dietrich, W.E. 1989. Source areas, drainage density, and channel initiation. *Water Resources Research* **25**, 1907–1918.

Montgomery, D.R. and Dietrich, W.E. 1994. Landscape dissection and drainage area-slope thresholds. In *Process Models and Theoretical Geomorphology*, ed. M.J. Kirkby, 221–246. Chichester: Wiley.

Received 6 September 2011
Accepted 25 October 2011